A Stochastic Integrated Approach to Parameter Estimation Using Geophysical Data

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RESEARCH OBJECTIVES

Subsurface investigations often require characterizing hydrogeological and geochemical parameters. Well-log or core methods for collecting these data are invasive and laborious, and are therefore rarely acquired at a sufficient spacing for describing field conditions. Integrated approaches, which combine multiple sources of information such as wellbore and geophysical measurements, offer great potential for improved, minimally invasive, and cost-effective characterization. Deterministic integration methods, however, are limited because of their inability to solve for a large number of unknown parameters, or to find a global optimal solution, or to describe the uncertainty associated with those parameters. We have developed a stochastic integrated approach that overcomes these limitations, based on the Markov chain Monte Carlo (MCMC) method. This approach has been applied to two different data sets in order to demonstrate the benefits of the method for integrating multiple sources of information.

APPROACH

Our integration framework is based on a Bayesian estimation approach. Within this framework, all unknown quantities are considered as random variables, and observable parameters are considered as data with measurement errors. The unknown variables and the known data are linked by geophysical forward models, rock physical relationships, and the site-specific cross correlations between all the parameters. Those variables, data, and relationships together define a joint conditional probability function (or posterior probability function). Our goal was to obtain the marginal posterior probability function for each unknown variable by conditioning on all the available information. Since analytical methods are not tractable when the joint probability function includes such a large number of unknown variables and when the relationships are very complicated, we use the MCMC method to obtain many samples for each unknown random variable. Using the generated samples, the mean, variance, prediction intervals, and posterior probability function of the unknown variable can be calculated.

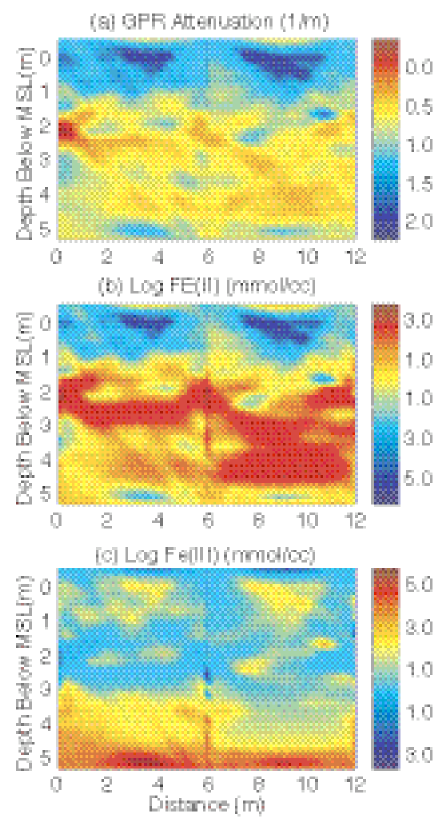

Figure 1. An example illustrating the use of our stochastic integration approach for geochemical parameter estimation. In this study, ground penetrating radar attenuation tomographic data (a) and other types of wellbore data were used to estimate logarithmic extractable Fe(II) (b) and Fe(III) (c) concentrations along a two-dimensional cross section.

ACCOMPLISHMENTS

We employed the developed stochastic model with crosshole ground-penetrating radar attenuation data to estimate sediment geochemical parameters at the South Oyster Bacterial Transport Site in Virginia (Figure 1). We also employed the method with crosshole seismic and electromagnetic data to estimate reservoir parameters, such as porosity and water saturation. Results from the two case studies showed that the developed method was more accurate, flexible, and efficient than deterministic approaches for integrating multiple sources of parameter-estimation information.

SIGNIFICANCE OF FINDINGS

We have developed a general framework that can be used to integrate various types of data sets for parameter estimation. This is the first effort to use minimally invasive and cost-effective geophysical data to aid in estimation of field-scale geochemical parameters. The methodology is particularly advantageous for use with data sets involving a large number of variables and complicated relationships between the variables.

RELATED PUBLICATIONS

Chen, J., S. Hubbard, Y. Rubin, C. Murray, E. Roden, and E. Majer, Geochemical characterization using geophysical data: A case study at the South Oyster Bacterial Transport Site in Virginia. Water Resources Research, 2003 (in press).

Chen, J., and M.G. Hoversten, Joint stochastic inversion of geophysical data for reservoir parameter estimation. 73rd Annual International Meeting, Society of Exploration Geophysics, 2003 (submitted).

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